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Heterosis and combining ability for grain and biomass yield in sorghum hybrids for the semi-arid lowlands of Eastern Kenya

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Sorghum [*Sorghum bicolor* (L.) Moench] is an important cereal crop used for food, feed, and industrial raw material. In Kenya, it's a food and nutritional security crop in the semi-arid areas which are prone to maize crop failures. The study aimed at estimating the combining ability and heterosis for grain and biomass yield among sorghum hybrids. Thirty- four F_1 sorghum hybrids, their parents and a check were evaluated at two KALRO research centers in Kenya during the 2014-2015 cropping seasons. Square lattice trial design with three replications was used and fourteen agro-morphological traits studied at each location. The combined analysis of variance showed highly significant differences (p<0.001) for genotypes and locations for all traits, except for leaf length. Fresh biomass yield, panicle exertion, and plant height had high heritability, genotypic coefficient of variation (GCV) and genetic advance (GA %) showing the predominance of additive gene effect in their inheritance, hence these traits can be improved through direct phenotypic selection. Hybrid parents ICSR 89058, ICSV 700 and ICSR 160 were good general combiners for earliness, biomass and grain yield respectively. The highest grain and biomass yielders were ATX 623 x Macia and ICSA 206 x IESV 91104DL respectively. High magnitudes of SCA effect coupled with high heterobeltiosis, mean and standard heterosis for grain and biomass yield were noted in hybrids ATX 623 x Macia and ICSA 11035 x Macia respectively. These hybrids can be promoted for on-farm testing and possible release for food and fodder. Therefore, the improvement of sorghum grain and forage yields in the semi-arid areas of Kenya can be done simultaneously through the exploitation of heterosis by developing hybrids.

Key words: Combining ability, heritability, heterobeltiosis, heterosis, additive gene effect, restorers.

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INTRODUCTION

Sorghum is an important food and feed crop grown in more than 90 countries in the world. It is utilized as food in Africa and India and as feed in the Americas, Europe and Australia (Ashok et al., 2011). Sorghum remains an important crop in the arid and semi-arid (ASALs) areas of the world. The crop is characterized by; a C4 photosynthetic pathway leading to high water use efficiency, tolerance to longer periods of waterlogging than maize (Muturi, 2013), extensive root system, waxy bloom on the leaves that reduce evapotranspiration and recovery growth after water stress (Muui et al., 2013). As a result, sorghum is able to survive well in semi-arid areas.

Sorghum plays a critical role as a food and nutritional security crop in the semi-arid Eastern, Nyanza, and Coastal parts of Kenya which are prone to maize crop failures. In Kenya, Sorghum grain is used in making fermented and unfermented porridge, beverage, ugali, pilau, chapati, cakes, cookies, and biscuits. The grain is also used directly for poultry feeding. The stalks are used for animal feed, thatching, and fuel (Muturi, 2013 and Muui et al., 2013). The use of sorghum grain to supplement barley in the brewing industry has increased sorghum demand in Kenya. There is a greater deficit of sorghum grain in Kenya with an annual demand of 40,000MT in the brewing industry and 200,000MT in the feed industry (Waikwa, 2016). However, the total sorghum annual production in Kenya was 117,000MT by the year 2016. The production in the farmers' fields is too low to satisfy this demand.

Africa contributes more than 60 % of the land area under sorghum but despite this, the yields have remained low at 0.85 tha-1 (Muui et al., 2013). The low yields are due to the use of farmer's self-saved seed of open-pollinated varieties, drought, high temperatures, poor agronomic practices, Striga parasitic weed, fungal diseases, birds and insects (Muii et al, 2013 and Muturi, 2013). Drought at grain filling is the most devastating abiotic stress in sorghum production that causes yield losses ranging from 45% to 50% (Wortmann et al., 2009). In order to increase sorghum yields in Africa, the improvement of sorghum for grain quality and resistance to biotic and abiotic stresses has to be done on high yielding backgrounds mainly through hybrid breeding.

The availability of stable cytoplasmic genetic male sterility (CGMS) system has made sorghum hybrid production possible. More than 700 A/B lines and 922 restorer lines with different traits are available at ICRISAT India for use in hybrid making. The CGMS system is of no use if the produced hybrids are not heterotic, in addition, there should be good combining ability between CGMS seed parents and their restorers. The seed and pollinator parents should also be well adapted to the environmental conditions in the areas where hybrid production is targeted for ease of seed production.

According to Nyadanu and Dikera (2014), the knowledge of genetic variability, heritability, and the correlation between economically important traits is a pre-requisite for the selection and development of high yielding well-adapted varieties. The proper selection of hybrid parents greatly depends on their combining ability. Different heterosis levels for grain yield have been reported in sorghum hybrids evaluated in Kenya. However, the information on heterosis and the combining ability of the new A-lines and the adapted restorer lines for grain and biomass yield is scanty. High yielding sorghum varieties are preferred in the semi-arid areas of Kenya. However, the hybrids are not commercially available and the information on their drought tolerance is also scanty.

Therefore, the present study aimed at establishing the magnitude of heterosis, combining ability and genetic parameters for grain and biomass yield in sorghum hybrids developed using ICRISAT- India and ICRISAT-Nairobi inbred parents for the semi-arid areas of Kenya.

MATERIALS AND METHODS

Description of the study sites

The study was conducted at two Kenya Agricultural and Livestock Research Organizations (KALRO) Stations; Kiboko and KampiyaMawein 2014 long rain and 2014/15 short rain seasons. The trials were rain fedwithsupplementary irrigation done atKiboko.Kiboko is found along Nairobi- Mombasa highway. It is located at longitude 37.75^{o}E and latitude 3.15^{o}S with an elevation of 975m *asl*.The climate is semi-arid with a bimodal rainfall of 530mm annually. The mean minimum and the mean maximum temperature is 14.3^{o}C and 35.1^{o}C respectively. The soils at Kiboko are sandy loams. KampiyaMawe is situated at longitude37^{o}40'E, and latitude 1^{o}57$^{'}$S with an altitude of 1125m *asl*.The area receives 643mm of rainfall annually with mean minimum and maximum temperatures of 14^{o}C and 31^{o}C respectively. The soils at KampiyaMawe are chromic luvisols.

Genetic materials and experimental design

Forty-six inbred lines (34 CGMS lines from India and 12 restorer lines from Kenya) were crossed in a North Carolina Mating Design I at Kiboko in 2013/14 short rain season. The resulting 34 F_1 hybrids with their 46 parents were evaluated along with the check Seredo in a 9 x 9 square lattice design. The experiment was replicated three times at each location. The list of the hybrids is shown in Table 1.

Each genotype was sown in a 2- row plot of 4m length covering an area of $6m^2$. The plots had inter-row and intra-row spacing of 0.75m and 0.2m respectively. A light layer of soil was used to cover the drilled seed. Thinning was done at 21 days after emergence to give a plant density of 67,134 plants ha^{-1}. At Planting, Di-Ammonium Phosphate fertilizer was applied at the rate of $87kgha^{-1}$. Urea fertilizer was top dressed at the rate of $54kgha^{-1}$ 30 days after crop emergence. Standard agronomic practices in sorghum were followed to raise a healthy crop. Four panicles were bagged in each plot to access fertility restoration. At physiological maturity, the panicles were cut from the stalks. The stalks without panicles were then cut at approximately 2cm from the ground and weighed to assess the fresh biomass weight.

Data collection

Observations were made on five randomly selected plants for; plant height (cm), waxy bloom (score 1-9), leaf length (cm), leaf width (cm), panicle exertion (cm), panicle length (cm), panicle width (cm) and stem girth (cm). Data on grain yield (t/ha), fresh biomass yield (t/ha) and days to 50% flowering were recorded on whole plot basis. Data collection was done at the appropriate crop growth stage as described in the sorghum descriptor by IBPGR and ICRISAT (1993).

Statistical analysis

Analysis of variance was done in GenStat V18 using a model adopted from Bondari, (2013).

$$Y_{ijk} = \mu + G_i + E_j + GE_{ij} + B_{jk} + g_{ijk}$$

Where: Y_{ijk}= Observed genotypic performance; μ= Overall trial mean; G_i = effect of the i^{th} genotype; E_j = effect of the j^{th} environment; GE_{ij} = interaction effect of the i^{th} genotype with the j^{th}Environment; B_{jk} = effect of the k^{th} replication in the j^{th} environment; g_{ijk} = random experimental error.

Mid- parent heterosis (MPH) and heterobeltiosis/ better-parent (BPH) heterosis were estimated according to Hallauer*et al*. (2010) whereas standard heterosis was computed according to Fehr, (1987) as follows;

$$MPH = \left[F1 - \frac{(P1 + P2)}{2}\right] X100\%$$

$$BPH = \left[\frac{(F1 - BP)}{BP}\right] X\ 100\%$$

$$SH = \left[\frac{(F1 - Check)}{Check}\right] X\ 100\%$$

Where: MPH, BPH, and SH are mid- parent, better-parent and standard heterosis respectively; F_1 is the observed mean of progenies; P1&P2 are the observed means of the parents, BP is the means of the superior parent, check = commercial variety.

Phenotypic and genotypic coefficients of variation were estimated using the formula proposed by Singh and Chaudhary (1985) whereas the broad sense heritability (h^2) was estimated on genotype mean basis as described by Allard (1960) as follows;

$$PCV = \frac{\delta_p}{\bar{x}} x\ 100\%$$

$$GCV = \frac{\delta_g}{\bar{x}} X\ 100\%$$

$$h^2 = \frac{\delta^2 g}{\delta^{2p}} X\ 100\%$$

Where: PCV is the phenotypic coefficient of variation, GCV is the genotypic coefficient of variation,δp is the phenotypic standard deviation, δg is the genotypic standard deviation, $\bar{X}$ is the phenotypic trait population mean, h^2 is heritability, $\delta^2 p$ is the phenotypic variance and $\delta^2 g$ is the genotypic variance.

Combining ability data was analyzed using Restricted Maximum Likelihood (REML) procedure in NCD I of AGD-R *V*.3.0 (Analysis of Genetic Designs in R) described by Rodriguez *et al*., (2015).

RESULTS

Analysis of Variance

Analysis of variance (ANOVA) revealed genotypes to be highly significant ($P < 0.001$) for all characters. Seasonal effects were highly significant ($P < 0.001$) for most of the traits except for plant height. Locational effect differed significantly ($P < 0.001$) for all the traits except for leaf length and panicle exertion. Genotype by location interaction was highly significant ($P < 0.001$) for most traits except leaf width which was significant at ($P < 0.05$) (Table 2).

Mean performance of sorghum hybrids across locations

The flowering range of the hybrids was 66 to 82 days with a mean of 71 days. The earliest genotypes were ICSA 29015 x ICSR 89058, ICSA 11038 x KARI Mtama 1 and Seredo. On the contrary, the hybrid, ICSA 11036 x KARI Mtama 1 took the longest number of days to flower. The plant height range was 99 cm to 215cm with a mean of 159cm. The shortest hybrid was ICSA 11016 x Wahi (99cm)followed by ICSA 11036 x KARI Mtama 1 (115cm). The tallest hybrids were ICSA 29017 x ICSR

Table 1. List of sorghum hybrids and a commercial check used in the study

Entry no	Genotype	Status
1	ICSA 11019 x Hakika	Hybrid
2	ICSA 11013 x Hakika	Hybrid
3	ICSA 228 x Hakika	Hybrid
4	ICSA 11003 x ICSR 160	Hybrid
5	ICSA 11033 x ICSR 160	Hybrid
6	ICSA 11004 x ICSR 24008	Hybrid
7	ICSA 232 x ICSR 24008	Hybrid
8	ICSA 29007 x ICSR 24008	Hybrid
9	ICSA 29004 x ICSR 24010	Hybrid
10	ICSA 29005 x ICSR 24010	Hybrid
11	ICSA 29017 x ICSR 24010	Hybrid
12	ICSA 101 x ICSR 38	Hybrid
13	ICSA 29016 x ICSR 38	Hybrid
14	ICSA 75 x ICSR 38	Hybrid
15	ICSA 29011 x ICSR 89058	Hybrid
16	ICSA 29015 x ICSR 89058	Hybrid
17	ICSA 29001 x ICSV 700	Hybrid
18	ICSA 29002 x ICSV 700	Hybrid
19	ICSA 29003 x ICSV 700	Hybrid
20	ICSA 11040 x IESV 91104 DL	Hybrid
21	ICSA 206 x IESV 91104 DL	Hybrid
22	ICSA 25002 x IESV 91104 DL	Hybrid
23	ICSA 12 X IESV 92172 DL	Hybrid
24	ICSA 11036 x KARI Mtama 1	Hybrid
25	ICSA 11038 x KARI Mtama 1	Hybrid
26	ICSA 11039 x KARI Mtama 1	Hybrid
27	ICSA 11034 x Macia	Hybrid
28	ICSA 11035 x Macia	Hybrid
29	ICSA 11037 x Macia	Hybrid
30	ICSA 74 x Macia	Hybrid
31	ATX 623 x Macia	Hybrid
32	ICSA 11007 x Wahi	Hybrid
33	ICSA 11016 x Wahi	Hybrid
34	ICSA 11018 x Wahi	Hybrid
35	Seredo	Check OPV

24010 (215.1cm) and ICSA 29004 x ICSR 24010 (209.6cm). Panicle length ranged from 22 to 37cm whereas the width ranged from 5.7 to 11cm. Hybrid ICSA 11004 x ICSR 24008 (36.7cm) had longest panicle. The shortest panicles were revealed in ICSA 11036 x KARI Mtama 1 (21.8). More than 20 hybrids had an excellent fertility restoration of greater than 80% with the highest percentage recorded in ATX 623 x Macia (99.3%) andICSA 29015 x ICSR 89058 (99.2%). Hybrid ICSA 11038 x KARI Mtama 1 (0%) wascompletely sterile (Table 3). The grain yield ranged from 0.989 to 3.835tha^{-1}(Table 3). The maximum grain yield was obtained from hybrids ATX 623 x Macia (3.835tha^{-1}), ICSA 11004 x ICSR 24008 (3.826tha^{-1}) and

Table 2.ANOVA for yield and yield components of 81 sorghum genotypes evaluated at Kiboko and KampiyaMawe in 2014 long rains and 2014-15 short rain seasons

		Source of variation				
		Genotype (G)	Season (S)	Location (L)	Genotype x Location (GxL)	Error
	DF	80	1	2	160	480
Traits	Days to 50% flowering	185.9***	1307.5***	311.5***	13.8***	5.2
	Stem girth (cm)	1.7***	80.1***	8.6***	0.5***	0.4
	Waxy bloom (1-5)	1.2***	218.8***	69.0***	1.5***	0.5
	Productive tillers (Counts)	10.3***	4017.5***	33.5***	8.6***	4.5
	Fresh biomass yield (T/ha)	58.9***	188.0***	963.7***	20.5***	11.2
	Plant Height (cm)	9140.1***	5056.5ns	6443.4***	423.9***	238.9
	Leaf length (cm)	206.5***	311.2***	151.1ns	69.8***	52.1
	Leaf width (cm)	4.7***	71.1***	118.7***	1.6*	1.0
	Panicle length (cm)	93.5***	3190.5***	2274.6***	19.7ns	21.1
	Panicle width (cm)	9.9***	1892.8***	362.9***	3.5***	2.0
	Panicle exertion (cm)	172.8***	5812.7***	14.14ns	38.8***	12.1
	Lodged plants (counts)	121.7***	1295.2***	2049.1***	86.7***	15.8
	100 seed mass (gm)	1.0***	42.7***	4.3***	0.3***	0.2
	Grain yield (T/ha)	3.1***	51.6***	224.7***	2.0***	0.8

DF= degrees of freedom, ns= not significant at P≤0.001,* and *** significant at P≤0.05 and P≤0.001 probability levels respectively.

Table 3. Mean performance of sorghum hybrids evaluated at Kiboko and KampiyaMawe in 2014LR and 2014-15SR.

Yield rank	Genotype	DFL	PHT (cm)	PL (cm)	PW (cm)	SS %	SD (gm)	BYLD (T/ha)	GY (T/ha)
1	ATX 623 x Macia	69	166.2	29.0	6.7	99.3	2.4	10.259	3.835
2	ICSA 11004 x ICSR 24008	70	154.9	36.7	9.3	88.5	2.3	7.900	3.826
3	ICSA 11033 x ICSR 160	69	159.8	30.5	11.1	88.2	2.0	6.278	3.673
4	ICSA 29005 x ICSR 24010	71	200.3	26.2	9.0	88.4	2.3	10.802	3.656
5	ICSA 29011 x ICSR 89058	68	165.0	30.4	9.0	96.1	2.4	8.488	3.604
6	ICSA 11040 x IESV 91104 DL	71	193.5	24.8	7.8	91.4	2.8	11.490	3.497
7	ICSA 11037 x Macia	71	150.0	27.6	8.9	85.8	2.3	6.857	3.334
8	ICSA 12 X IESV 92172 DL	68	146.5	28.7	6.5	95.9	2.3	7.494	3.327
9	ICSA 29017 x ICSR 24010	70	215.1	25.6	8.1	85.9	2.1	12.223	3.305
10	ICSA 11003 x ICSR 160	69	163.2	30.0	8.9	92.1	2.5	6.901	3.287
11	ICSA 232 x ICSR 24008	72	149.8	30.8	9.0	97.8	2.0	8.531	3.171
12	ICSA 11035 x Macia	71	150.5	27.0	8.1	73.5	2.5	11.852	2.980
13	ICSA 29004 x ICSR 24010	70	209.6	26.1	8.1	93.6	2.3	10.829	2.904
14	ICSA 11034 x Macia	70	138.8	27.9	8.0	80.5	2.6	8.094	2.855
15	ICSA 29007 x ICSR 24008	74	159.8	30.0	7.8	92.1	2.2	6.968	2.830
16	ICSA 11038 x KARI Mtama 1	66	184.7	24.4	7.7	0.0	3.4	10.784	2.782
17	ICSA 29015 x ICSR 89058	66	158.0	28.5	7.2	99.2	2.3	4.241	2.613
18	Seredo (Check)	66	145.3	28.0	7.0	97.6	2.3	7.320	2.600

Table 4. continuation

19	ICSA 29001 x ICSV 700	78	188.9	22.3	6.7	97.3	2.4	11.176	2.573
20	ICSA 29002 x ICSV 700	81	195.1	22.4	6.9	48.4	2.3	11.566	2.557
21	ICSA 101 x ICSR 38	71	140.8	30.5	8.5	64.8	2.4	7.482	2.554
22	ICSA 206 x IESV 91104 DL	67	172.0	28.2	7.6	79.8	2.8	13.713	2.553
23	ICSA 75 x ICSR 38	68	169.4	34.0	7.2	93.4	2.2	5.704	2.513
24	ICSA 228 x Hakika	72	135.1	30.5	7.3	23.9	2.9	11.137	2.462
25	ICSA 29016 x ICSR 38	68	148.0	26.6	7.2	97.8	2.1	6.420	2.355
26	ICSA 74 x Macia	73	163.1	29.5	7.1	39.4	2.7	10.975	2.237
27	ICSA 11039 x KARI Mtama 1	67	184.0	24.2	7.8	3.3	3.3	7.829	2.196
28	ICSA 11019 x Hakika	74	138.8	27.2	6.8	85.0	2.8	11.549	2.133
29	ICSA 11016 x Wahi	74	99.5	25.0	5.7	31.0	2.8	8.986	2.104
30	ICSA 11007 x Wahi	74	134.3	30.1	5.9	76.8	2.6	7.642	2.018
31	ICSA 29003 x ICSV 700	79	177.3	22.6	6.9	59.8	2.7	11.716	1.909
32	ICSA 11018 x Wahi	73	126.1	29.6	7.4	88.2	3.0	7.691	1.829
33	ICSA 11013 x Hakika	74	121.2	30.7	8.9	33.8	2.8	8.056	1.641
34	ICSA 25002 x IESV 91104 DL	79	157.0	27.5	7.6	45.7	2.7	11.691	1.384
35	ICSA 11036 x KARI Mtama 1	82	115.0	21.8	6.2	17.7	2.9	13.403	0.989

DFL=days to flowering, PAS=Plant aspect score (1-5), NTIL=number of productive tillers, BYLD=biomass yield (tha-1), PHT= plant height (cm), PL= panicle length (cm), PW= panicle width (cm), PE= panicle exertion (cm), SS= seed set (%), SD= 100 seed mass (g), GY=grain yield (tha-1), LR=long rain season, SR= short rain season.

ICSA 11033 x ICSR 160 (3.673tha^{-1}). The lowest grain yield was obtained from ICSA 11036 x KARI Mtama 1 (0.989 tha^{-1}) and ICSA 25002 x IESV 91104 DL (1.384 tha^{-1}). The highest biomass yield was noted in ICSA 206 x IESV 91104 DL (13.713tha^{-1}), ICSA 11036 x KARI Mtama 1 (13.403 tha^{-1}) and ICSA 29017 x ICSR 24010 (12.223tha^{-1}). The superior hybrid for grain yield and biomass yield was ICSA 29017 x ICSR 24010 (Table 3).

Heterosis levels

The three types of heterosis *viz* heterobeltiosis, mid-parent, and standard heterosis were recorded with varied ranges for the studied characters (Table 4). Heterosis was recorded with both negative and positive magnitude for most of the traits except for standard heterosis of days to flowering (0-24%) and leaf width (1-38%) which were reported with only positive values. Most hybrids recorded positive (favorable) better- parent and mid-parent heterosis for plant height, panicle exertion, and panicle length. Most of the cross combinations revealed negative (favorable) better- and mid-parent heterosis for the days to flowering. Panicle exertion and the number of lodged plants recorded the highest heterosis values of up to 834% and 588% respectively (Table 4).

Estimates of heterobeltiosis, mid-parent, and standard heterosis for the 34 F_1 hybrids for the studied characters are presented in Table 5. The most favorable (negative) heterobeltiosis and mid-parent heterosis for days to flowering was displayed by the hybrids ICSA 29015 x ICSR 89058 and ICSA 29011 x ICSR 89058 (Table 5). The highest heterobeltiosis and mid-parent heterosis values for plant height were obtained in hybrids ATX 623 x Macia (52%) and ICSA 29001 x ICSV 700 (61%) respectively, followed by ICSA 11035 x Macia (38% and 55%). The highest standard heterosis for plant height was noted in ICSA 29017 x ICSR 24010 (48%) and ICSA 29004 x ICSR 24010 (44%). The lowest heterobeltiosis and mid-parent heterosis were recorded in ICSA 11036 x KARI Mtama 1 at -18% and -9% respectively.

The cross ATX 623 x Macia recorded the highest heterosis over mid, better parent and the check for grain yield (Table 5). Another cross ICSA 29011 x ICSR 89058 revealed positive better parent and mid-parent heterosis for grain yield at 39% and 49% respectively. These two hybrids also recorded heterosis for days to 50% flowering in the desirable direction. The hybrid ICSA 11036 x KARI Mtama 1 revealed the lowest better and mid-parent heterosis for grain yield at -60% and -57% respectively (Table 5). The hybrids ICSA 228 x Hakika (56%) and ICSA 11035 x Macia (46%) revealed the highest heterobeltiosis for biomass yield. The

Table 5: Heterosis ranges for 14 characters in sorghum hybrids evaluated at Kiboko and KampiyaMawe

Trait	**Range of heterosis values**			**Number of crosses showing positive heterosis**		
	BPH	MPH	SH	BPH	MPH	SH
Days to 50% flowering (counts)	-16 to 0%	-12 to 7%	0 to 24%	0	5	32
Fresh biomass Yield (t/ha)	-46 to 56%	-40 to 158%	-42 to 87%	19	26	27
Plant Height (cm)	-18 to 52%	-9 to 61%	-32 to 48%	28	31	25
Leaf length (cm)	-18 to 23%	-9 to 23%	-4 to 32%	22	28	32
Leaf width (cm)	-16 to 22%	-8 to 23%	1 to 38%	19	25	34
Panicle length (cm)	-14 to 32%	-13 to 34%	-22 to 31%	24	29	17
Panicle width (cm)	-28 to 30%	-20 to 40%	-20 to 59%	20	27	25
No. of leaves	-26 to 17%	-23 to 21%	-17 to 40%	5	9	25
Panicle exertion (cm)	-98 to 495%	-97 to 834%	-98 to 203%	27	29	22
% Seed set	-100 to 6%	-100 to 6%	-100 to 2%	3	8	2
No. of Lodged plants	-91 to 336%	-89 to 588%	-96 to 371%	17	25	22
100 seed mass (gm)	-40 to 26%	-13 to 39%	-13 to 49%	21	30	25
Grain weight /5 plants (g)	-42 to 60%	-41 to 66%	-33 to 97%	23	27	32
Grain yield (t/ha)	-60 to 57%	-57 to 57%	-62 to 48%	19	22	16

BPH=better parent heterosis, MPH=mid parent heterosis and SH=standard heterosis

Table 6: Heterobeltiosis, mid parent and standard heterosis values for 4 characters in 34 sorghum hybrids evaluated at Kiboko and Kampi ya Mawe in 2014 and 2015 seasons

	Heterobeltiosis				**Mid Parent Heterosis**				**Standard Heterosis**			
Hybrid name	**DFL**	**PHT**	**BY**	**GY**	**DFL**	**PHT**	**BY**	**GY**	**DFL**	**PHT**	**BY**	**GY**
ATX 623 x Macia	-6	52	27	57	-4	55	43	57	5	14	40	48
ICSA 101 x ICSR 38	-6	17	12	5	-4	22	28	24	8	-3	2	-2
ICSA 11003 x ICSR 160	-7	28	21	20	-6	38	36	37	4	12	-6	26
ICSA 11004 x ICSR 24008	-9	17	12	21	-6	23	24	38	6	7	8	47
ICSA 11007 x Wahi	-5	5	9	-3	-1	15	10	0	13	-8	4	-22
ICSA 11013 x Hakika	-5	7	13	-22	-1	12	24	-15	12	-17	10	-37
ICSA 11016 x Wahi	-4	-7	31	-9	0	-6	40	-4	12	-32	23	-19
ICSA 11018 x Wahi	-9	7	-14	-31	-4	13	-3	-23	10	-13	5	-30
ICSA 11019 x Hakika	-3	22	38	-12	0	23	49	-6	12	-4	58	-18
ICSA 11033 x ICSR 160	-6	25	15	34	-6	26	31	43	5	10	-14	41
ICSA 11034 x Macia	-5	27	0	17	-5	34	36	32	7	-4	11	10
ICSA 11035 x Macia	-4	38	46	22	-4	55	62	39	7	4	62	15
ICSA 11036 x KARI Mtama 1	0	-18	32	-60	7	-9	44	-57	24	-21	83	-62
ICSA 11037 x Macia	-11	23	-15	28	-7	30	-13	32	9	3	-6	28
ICSA 11038 x KARI Mtama 1	-11	32	27	3	-8	47	43	14	0	27	47	7
ICSA 11039 x KARI Mtama 1	-11	32	-8	-3	-8	48	12	-1	1	27	7	-16
ICSA 11040 x IESV 91104 DL	-7	14	19	18	-5	39	30	25	8	33	57	35
ICSA 12 X IESV 92172 DL	-7	36	-1	26	-7	38	21	38	4	1	2	28
ICSA 206 x IESV 91104 DL	-7	2	42	-3	-9	46	158	42	2	18	87	-2
ICSA 228 x Hakika	-11	19	56	17	-5	32	66	29	9	-7	52	-5
ICSA 232 x ICSR 24008	-8	12	17	0	-7	25	29	19	10	3	17	22
ICSA 25002 x IESV 91104 DL	0	-7	21	-48	5	19	44	-35	20	8	60	-47

Table 7. contiuation

ICSA 29001 x ICSV 700	-6	-2	-12	4	2	61	60	19	19	30	53	-1
ICSA 29002 x ICSV 700	0	1	-9	3	1	25	18	9	23	34	58	-2
ICSA 29003 x ICSV 700	-2	-8	-7	-23	1	19	23	-21	20	22	60	-27
ICSA 29004 x ICSR 24010	-6	12	-1	-6	-5	38	19	-5	7	44	48	12
ICSA 29005 x ICSR 24010	-5	7	-1	20	-5	39	33	49	7	38	48	41
ICSA 29007 x ICSR 24008	-12	-4	-26	12	-10	18	-16	13	12	10	-5	9
ICSA 29011 x ICSR 89058	-15	22	1	39	-10	23	16	49	3	14	16	39
ICSA 29015 x ICSR 89058	-16	17	-46	0	-12	23	-40	13	0	9	-42	0
ICSA 29016 x ICSR 38	-11	16	-19	-11	-9	20	-1	-7	3	2	-12	-9
ICSA 29017 x ICSR 24010	-13	15	12	9	-10	36	28	36	6	48	67	27
ICSA 74 x Macia	-12	6	-23	-9	-7	24	-2	-3	11	12	50	-14
ICSA 75 x ICSR 38	-11	22	-40	3	-9	31	-22	8	3	17	-22	-3

DFL=Days to 50% flowering, PHT=Plant height, GY- Grain yield (t/ha), BY- Fresh biomass yield (tha^{-1})

crosses ICSA 206 x IESV 91104DL (158%) and ICSA 228 x Hakika (66%) showed the highest heterotic effects over the mid-parent for biomass yield. The highest standard heterosis values for biomass yield were recorded in ICSA 206 x IESV 91104 DL (87%) and ICSA 29017 x ICSR 24010 (67%). Two crosses ICSA 29015 x ICSR 89058 and ICSA 75 x ICSR 38 recorded the lowest better, mid-parent and standard heterosis values for biomass yield (Table 5).

Genotypic and phenotypic coefficients of variation in sorghum hybrids and their parents

Sorghum hybrids and their parents recorded higher PCV estimates than the GCV estimates for all the fourteen quantitative traits evaluated. The estimates of PCV (range=21.1 to 208.8%)were high for the number of tillers, biomass yield, plant height, panicle length, panicle widthand exertion, number of plants lodged, 100 seed mass and grain yield (Table 6). Medium PCV ranging from 13% to 20% was estimated for stem girth, leaf length and leaf width in hybrids and their parents. Minimum PCV scores were estimated for days to 50% flowering (7.9%) (Table 6).
High GCV scores ranging from 21.9% to 107.3%were recorded for the number of productive tillers, biomass yield, plant height, panicle exertion, and the number of lodged plants in hybrids and their parents. Medium GCV estimates were noted forpanicle width, panicle length, and 100 seed mass. Low GCV estimates ranging from 4.9% to 9.8% were recorded for leaf length and days to 50% flowering.

Heritability and genetic advance for the sorghum hybrids and their parents

The results in Table 6 show the estimates of heritability and genetic advance. High heritability (h^2) estimates among the hybrids were observed for days to flowering (90.6%), panicle exertion (82%), plant height (81%) and biomass yield (65.8%). High heritability estimates were revealed among the parents for the same traits with scores of 87.8%, 76.3%, 85.6%, and 63.3% respectively. However, low heritability was noted for leaf length (10.1%) and lodged plants (12.3%) for the hybrids, and the number of productive tillers (26.9%) among the parents. Moderate heritability values ranging from 32.5% to 59.6% were observed for panicle length, panicle width, 100 seed mass, stem girth, leaf width, and grain yield.

Medium to high genetic advance (12.6% to 192.9%) was reported in all 14 quantitative traits for the hybrids and their parents except for leaf length which recorded low GA% (3.2%). The genetic advance was highest for panicle exertion (192.9%) followed by lodged plants (126.8%), fresh biomass yield (63.7%), number of productive tillers (58.9%), plant height (50.9%), 100 seed mass (30.7%), panicle width (24%) and grain yield (23.6%)among the parents (Table 6). High GA% was observed for most of the traits among the hybrids except for days to 50% flowering (16.9%), stem girth (17.8%), leaf width (12.6%) and panicle length (19.3%) which recorded moderate GA% (Table 6). Traits that recorded medium to high GA% values among the hybrids had high GA% values among their parents (Table 6).

General combining ability effects for male parents at Kiboko and Kampiya Mawe

Results for GCA scores for Kiboko and KampiyaMawe are shown in Tables 7 and 8. The estimates of GCA effects revealed that male parents ICSR 89058 (-2.45), ICSR 38 (-1.39) and IESV 92172DL (-1.19) were good general combiners forearly flowering at Kiboko.The

Table 8. Estimates of genetic parameters for the studied traits in sorghum hybrids and their parents at Kiboko

	Parents					**Hybrids**				
Trait	**Means**	**H^2**	**PCV%**	**GCV%**	**GA%**	**Means**	**H^2**	**PCV%**	**GCV%**	**GA%**
DFL	76	87.8	7.9	7.4	14.3	72	90.6	9.1	8.6	16.9
SG	5.9	46.8	14.4	9.8	13.8	5.8	58.3	14.8	11.3	17.8
NTIL	3	26.9	106.6	55.2	58.9	3	38.4	95.8	59.4	75.8
BY	7.930	63.3	48.8	38.9	63.7	10.182	65.8	44.3	35.9	60.1
PHT	123.8	85.6	28.9	26.7	50.9	161.0	81.4	24.3	21.9	40.8
LL	67.7	54.0	13.0	9.5	14.4	71.4	10.1	15.5	4.9	3.2
LW	8.1	48.3	20.0	13.9	19.9	8.4	42.7	14.4	9.4	12.6
PL	27.6	33.2	21.1	12.2	14.4	29.9	38.0	24.6	15.2	19.3
PW	8.0	44.7	26.1	17.4	24.0	9.0	52.3	25.2	18.2	27.2
PE	3.8	76.3	122.7	107.2	192.9	9.6	82.0	95.6	86.6	161.5
LO	2	32.9	187.2	107.3	126.8	2	12.3	208.8	73.3	53.0
SD	2.3	59.6	25.0	19.3	30.7	2.7	58.5	20.6	15.8	24.8
GW	335.6	32.5	31.1	17.8	20.9	411.9	37.9	37.3	23.0	29.1
GY	2.927	32.1	35.7	20.2	23.6	3.195	54.2	49.8	36.7	55.6

DFL-days to 50% flowering, SG- stem girth, NTIL-number of productive tillers, BY- Fresh biomass yield, PHT- Plant height, LL- leaf length, LW- Leaf width, PL-Panicle length, PW- Panicle width, PE- Panicle exertion, LO- number of lodged plants, SD- 100 seed mass, GW- Grain weight on 5 sampled plants, GY- Grain yield (t/ha), Means- grand means, δ^2g- genotypic variance, δ^2e- environment variance, δ^2p- phenotypic variance, H^2- Broad sense heritability, PCV%- Phenotypic coefficient of variation, GCV%- Genotypic coefficient of variation, GA% -Genetic advance as a percentage of the mean.

Table 7. Estimates of general combining ability for 14 traits in 12 hybrid male parents at Kiboko

Parents	**DFL**	**BYLD**	**GY**	**LL**	**LW**	**LO**	**NTIL**	**PE**	**PL**	**PW**	**PH**	**SS**	**SD**	**SG**
Hakika	0.59	0.39	-0.42	0.63	0.34	-1.17	1.17	-6.44	1.76	0.02	-21.87	-19.82	0.21	0.01
ICSR160	-0.97	-1.54	0.28	0.51	-0.03	1.15	0.29	-0.21	1.79	1.59	-0.43	11.75	-0.26	0.00
ICSR24008	0.23	-1.46	0.39	-0.40	0.21	1.27	-0.09	-1.73	2.66	1.05	-1.50	16.14	-0.22	0.00
ICSR24010	-0.86	2.64	0.62	-0.60	0.03	-0.02	0.44	5.04	-1.13	0.63	42.39	12.37	-0.19	-0.01
ICSR38	-1.39	-1.45	-0.05	-0.31	-0.26	1.75	-0.01	3.47	2.39	0.10	-3.48	9.26	-0.26	-0.01
ICSR89058	-2.45	-1.78	0.24	-0.29	-0.20	0.20	0.39	6.05	1.35	0.18	1.43	17.05	-0.18	-0.01
ICSV700	5.29	1.44	-0.30	-1.70	0.03	-1.13	-0.67	-5.89	-3.85	-0.85	18.18	-3.93	-0.06	0.00
IESV91104DL	0.29	1.27	-0.18	1.43	0.10	-0.47	0.07	-0.90	-2.49	-0.17	10.88	1.35	0.28	0.00
IESV92172DL	-1.19	-0.28	0.23	-0.51	-0.36	0.01	-0.42	4.66	-0.10	-0.71	-9.66	12.23	-0.07	0.00
KARI Mtama1	-0.53	1.52	-0.72	-0.41	-0.12	-0.65	0.07	0.33	-3.91	-0.70	-1.46	-52.13	0.54	0.00
Macia	-0.34	0.42	0.31	1.42	0.29	0.12	-0.43	1.12	0.40	0.07	-4.50	1.90	-0.02	0.01
Wahi	1.34	-1.16	-0.40	0.22	-0.03	-1.04	-0.80	-5.51	1.14	-1.20	-29.99	-6.17	0.22	0.01

DFL-days to 50% flowering, SG=stem girth (cm), NTIL=number of productive tillers, BYLD= Biomass yield (tha^{-1}), PH=plant height (cm), LL=leaf length (cm), LW=leaf width (cm), PL=panicle length (cm), PW=panicle width (cm), PE=panicle exertion (cm), SS=seed set%, LO=number of plants lodged, SD=100 seed mass (g), GW=grain weight per 5 sampled plants (g) and GY= grain yield (tha^{-1}).

Table 8. Estimates of general combining ability for 12 traits in 12 hybrid male parents at KampiyaMawe

Parents	DFL	BYLD	GY	LL	LW	LO	NTIL	PL	PW	PH	SD
Hakika	1.37	2.11	-0.31	-0.15	0.39	-8.92	-0.02	0.53	-0.14	-21.30	0.26
ICSR160	-1.49	-1.38	0.25	0.80	-0.05	3.55	0.03	1.38	0.40	2.53	-0.12
ICSR24008	0.19	-0.08	0.16	-0.93	0.12	0.19	0.08	0.61	0.06	-5.69	-0.48
ICSR24010	-0.42	-0.26	0.04	-1.20	-0.15	4.46	-0.02	-1.57	0.06	27.18	-0.30
ICSR38	-1.60	-1.97	-0.07	0.09	-0.31	5.56	-0.02	1.19	-0.25	-12.76	-0.22
ICSR89058	-1.59	-1.27	-0.08	-1.23	-0.12	2.76	-0.02	0.73	0.10	0.45	0.00
ICSV700	2.76	2.34	-0.13	0.54	-0.10	-0.23	-0.03	-3.05	-0.04	26.19	0.04
IESV91104DL	0.23	0.22	0.08	2.30	0.15	0.94	0.08	-0.74	0.00	15.53	0.25
IESV92172DL	-0.73	-1.61	0.01	-0.07	-0.23	3.99	0.04	1.21	-0.09	-4.93	-0.27
KARI Mtama1	0.64	0.90	0.07	-1.02	-0.15	-4.43	-0.03	-1.79	0.13	7.37	0.56
Macia	-0.46	0.63	0.16	0.72	0.22	-0.27	-0.04	0.32	-0.13	-9.31	-0.03
Wahi	1.09	0.38	-0.19	0.14	0.23	-7.61	-0.03	1.19	-0.10	-25.25	0.30

DFL-days to 50% flowering, SG=stem girth (cm), NTIL=number of productive tillers, BYLD= Biomass yield (tha^{-1}), PH=plant height (cm), LL=leaf length (cm), LW=leaf width (cm), PL=panicle length (cm), PW=panicle width (cm), PE=panicle exertion (cm), SS=seed set%, LO=number of plants lodged, SD=100 seed mass (g), GW=grain weight per 5 sampled plants (g) and GY= grain yield (tha^{-1}).

good combiners for earliness at KampiyaMawewere ICSR 38 (-1.60), ICSR 89058 (-1.59), ICSR 160 (-1.49).The good general combiners for biomass yield were ICSR 24010 (2.64), KARI Mtama 1 (1.52) and ICSV 700 (1.44) at Kiboko.The best general combiners for biomass yield at KampiyaMawe were ICSV 700 (2.34),Hakika (2.11) and IESV 91104DL (1.27). Most desirable GCA effects for grain yield were exhibited in ICSR 24010 (0.62), ICSR 24008 (0.39) and Macia (0.31) at Kiboko. The best general combiners for grain yield at KampiyaMawe were ICSR 160 (0.25), ICSR 24008 (0.16) and Macia (0.16).However, the scores were low. The highest positive GCA effects for plant height were shown by ICSR 24010 and ICSV 700at Kiboko and KampiyaMawerespectively. The lowest GCA for plant height was recorded by Wahi and Hakikaat both locations (Table 7 and 8). Positive GCA effects for 100 seed mass was exhibited in KARI Mtama 1 (0.54) and Wahi (0.3) at Kiboko and KampiyaMawe respectively.

Specific combining ability effects for yield and its related traits across locations

The results of the combined SCA effects are shown in Table 9. The SCA effects for days to 50% flowering were recorded in desirable direction by 20 of the 34 hybrids. The crosses that showed earliness in flowering were ICSA 206 x IESV 91104DL (-5.69) and ICSA 11038 x Mtama1 (-4.96) and ICSA11039 x KARI Mtama1 (-4.18).

The results further revealed that the hybrid ICSA 11036 x KARI Mtama 1 (8.8) which recorded the highest SCA effect for days to 50% flowering also displayed the highest positive SCA effect for biomass yield (1.36) (Table 8). Other hybrids with high SCA effects for biomass yield were ICSA 11040 x IESV 91104DL (1.25) and ICSA29017 x ICSR24010 (1.03). The highest estimate of positive SCA effects for grain yield was recorded in hybrids ATX 623 x Macia (0.29), ICSA 11040 x IESV 91104DL (0.25) and ICSA 29011 x ICSR 89058 (0.17). However, the SCA scores were of lower magnitude. Hybrids ICSA 75 x ICSR 38 (1.88) and ICSA 11007 x Wahi (1.76) displayed the highest SCA effects for panicle length. High SCA effects for plant height were recorded in ICSA 11038 x KARI Mtama 1 (21.66), ICSA 11039 x KARI Mtama 1 (20.89) and ICSA 11040 x IESV 91104DL (16.40) whereas the lowest SCA effects for plant height were recorded in ICSA 11036 x KARI Mtama 1 (-41.02) and ICSA 11016 x Wahi (-27.12).

Estimates of components of variance for yield and its related traits across locations

Additive variance was higher than dominance variance in most of the studied traits as shown in Table 10. Degree of dominance was more than unity in days to 50% flowering, leaf length and stem girth with values of 1.02, 1.38 and 1.1 respectively.

Table 9. Specific combining ability effects for females in male parents across locations

Genotype	DAF	BY	GY	LL	LW	PE	PL	PH	SS
ICSA11013 x Hakika	1.26	-0.62	-0.19	-0.87	0.14	-1.92	0.59	-15.93	-8.92
ICSA11019 x Hakika	1.12	0.65	-0.02	1.67	-0.1	-0.93	-0.76	3.75	24.32
ICSA228 x Hakika	-0.44	0.47	0.03	0.27	0.16	-0.01	0.56	-2.59	-30.06
ICSA11003 x ICSR160	-1.52	-0.26	0.02	0.92	0.02	2.05	0.2	1.47	6.31
ICSA11033 x ICSR160	-0.89	-0.54	0.12	0.91	-0.04	-2.03	0.31	-1.18	2.22
ICSA11004 x ICSR24008	-2.1	-0.49	0.13	0.58	-0.08	-0.39	0.22	-4.02	2.59
ICSA232 x ICSR24008	0.81	0.23	0.09	-2.35	0.09	-0.25	0.48	-3.94	6.88
ICSA29007 x ICSR24008	1.97	-0.29	-0.06	-0.1	0.09	0.24	-0.08	6.13	2.27
ICSA29004 x ICSR24010	-0.5	-0.05	0.01	-0.79	-0.06	1.45	-0.05	12.22	6.82
ICSA29005 x ICSR24010	-0.26	-0.06	0.07	-0.61	0.05	0.53	0.04	0.6	2.43
ICSA29017 x ICSR24010	-0.61	1.03	0.11	-1.09	0	0.28	-0.43	11.46	-0.15
ICSA101 x ICSR38	0.74	0.33	-0.07	0.36	-0.09	-1.39	0.27	-12.33	-15.84
ICSA29016 x ICSR38	-1.91	-0.44	0.04	-0.94	-0.01	0.36	-1.54	-5.86	13.26
ICSA75 x ICSR38	-2.03	-0.76	-0.01	-0.01	-0.04	2.57	1.88	13.51	9.21
ICSA29011 x ICSR89058	-1.32	0.51	0.17	-0.16	-0.03	2.49	0.62	4.82	5.03
ICSA29015 x ICSR89058	-3.3	-1.39	-0.12	-1.63	-0.06	0.07	-0.27	-4.24	7.35
ICSA29001 x ICSV700	2.27	0.11	-0.01	-3.12	-0.06	-1.67	-0.75	6.76	23.98
ICSA29002 x ICSV700	4.26	0.47	0.03	0.73	0.13	0.03	0.34	13.11	-18.64
ICSA29003 x ICSV700	2.66	0.35	-0.13	-0.65	-0.06	-0.68	-0.7	-6.03	-8.25
ICSA11040 x IESV91104DL	-0.66	1.25	0.25	3.68	0.06	0.94	-0.46	16.4	14.49
ICSA206 x IESV91104DL	-5.69	-1.45	-0.04	-3.86	-0.21	2.41	-0.66	7.08	12.43
ICSA25002 x IESV91104DL	6.93	0.71	-0.24	5.65	0.23	-4.19	0.53	-15.02	-25.8
ICSA12 x IESV92172DL	-2.19	-0.38	0.07	-1.06	-0.21	1.91	0.18	-5.09	9.25
ICSA11036 x KARI Mtama1	8.8	1.36	-0.32	-2.1	-0.02	-5.53	-1.01	-41.02	-2.27
ICSA11038 x KARI Mtama1	-4.96	0.12	0.12	-0.35	-0.05	2.97	0.06	21.66	-18.9
ICSA11039 x KARI Mtama1	-4.18	-0.77	0.01	0.67	0.01	2.86	-0.04	20.89	-16.81
ATX623 x Macia	-1.9	0.29	0.29	0.93	-0.05	3	0.32	11.3	21.25
ICSA11034 x Macia	-0.75	-0.67	0	1.76	-0.08	-0.14	-0.06	-13.11	5.12
ICSA11035 x Macia	-0.36	1	0	-1.88	0.18	-1.22	-0.47	-4.59	-1.8
ICSA11037 x Macia	0.5	-0.97	0.1	3.24	0.02	-0.77	-0.31	-4.94	8.69
ICSA74 x Macia	1.76	0.61	-0.27	-0.45	0.06	-0.45	0.6	7.22	-31.81
ICSA11007 x Wahi	1.53	-0.33	-0.08	-1.2	-0.03	0.08	1.76	13.27	7.9
ICSA11016 x Wahi	1.09	0.27	-0.02	1.36	-0.16	-2.29	-1.54	-27.12	-31.25
ICSA11018 x Wahi	-0.13	-0.31	-0.09	0.48	0.22	-0.4	0.16	-4.63	18.69

Table 10. Estimates of genetic parameters in the 34 sorghum hybrids across locations

Parameter	DAF	BY	GY	LL	LW	PE	PL	PW	PH	SS	SD	SG
Additive Variance	22.5	11.3	1.0	8.6	0.6	54.2	22.5	1.8	1719	2044	0.4	0.1
Dominance Variance	23.4	0.0	0.0	16.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Environmental Variance	3.1	5.3	0.7	10.0	0.5	14.2	6.1	2.4	117.1	102.8	0.1	0.2
Broad Heritability	0.9	0.7	0.6	0.7	0.6	0.8	0.8	0.4	0.9	1.0	0.8	0.6
Narrow Heritability	0.5	0.7	0.6	0.3	0.6	0.8	0.8	0.4	0.9	1.0	0.8	0.3
Degree of dominance	1.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1

DISCUSSIONS

The presence of highly significant mean squares (P < 0.001) of genotypes for yield and its contributory traits indicated that large variability existed within the germplasm. Therefore, these genotypes had a good potential of developing hybrids with high grain and biomass yield. Similar findings were also reported in sorghum by (Abdus*et al* 2012; Nyadanu and Dikera 2014; and Taye*et al* 2016). Highly significant mean squares (P < 0.001) for environment and seasons showed the presence of soil and climatic variations between the two locations. Therefore, future evaluations of sorghum hybrids should be done at both locations to give conclusive results. Similar findingswere reported in sorghum hybrids by Ezzat*et al.*(2010).

The hybrids had variedyield performances hence selection of superior hybrids based on *per se* performance is possible. The superior grain yielders among the hybrids were developed from high yielding restorers hence selection of male parents should be based on their *perse* performance. Similar observations were made by Ghorade and Dipali (2007) in India.

Most of the hybrids yielded better than the commercial check Seredo and some were superior in more than one trait. Hybrids that had high grain yield but poor in other traits could be used as a source of genes in breeding programs to improve lines that have desirable characters but poor in yield. Thesterile cross ICSA 11038 x KARI Mtama 1(0% seed set) with superior performance for biomass yield and 100 seed mass could be used in generating CGMS seed parents for use in future hybrid breeding programs. Early maturing, high yielding, short hybrids with superior fertility restoration could be promoted for on-farm testing and eventual release for cultivation. Similar findings on differential performance of sorghum hybrids were reported by Batista et al. (2017).

Utilization of heterosis is important in improving grain and biomass yields in sorghum.Negative heterobeltiosis for days to flowering was revealed in 31 hybrids whereas 27 of them had negative mid-parent heterosis for the trait, indicating that heterosis was based on non-additive gene action. The results show that hybrids were early flowering than the parents. Positive standard heterosis for grain yield was revealed in 16 hybrids. However, of the 16 only four hybrids ATX 623 x Macia, ICSA 11004 x ICSR 24008, ICSA 11033 x ICSR 160, and ICSA 29005 x ICSR 24010 showed the recommendedyield advantage of greater than 40% over the released check. These hybrids also showed positive standard heterosis for biomass yield, plant height, leaf length and width, panicle length and exertion, and seed mass. These hybrids can be evaluated further under on-farm testing. Similar findings were reported by Jadhav and Deshmukh (2017). Heterosis for biomass yield and its contributory traits was recorded with positive magnitude in most of the cross combinations. The three types of heterosis for grain and biomass yield were reported with both positive and negative magnitudes. Therefore, increasing sorghum productivity in the ASALs of Kenya greatly relies on hybrid development. Our findings agreed well with those of Ringo *et al*. (2015), Sayed and Mahdy(2016) &Ghulam and Shahid (2014).

None of the male parents was a good general combiner for all traits. The differential ranking of parents for GCA at Kiboko and KampiyaMawe showed that the environment affects the GCA of male parents. Therefore, the selection of parents should be done after testing them in different environments to classify them as generally and specifically adapted. Similar findings were reported by Makanda (2009). Both positive and negative effects of GCA were reported for all traits. Early maturing genotypes are preferred in escaping terminal drought which is more prevalent in the ASALs. Restorer parents ICSR 89058, ICSR 38, IESV 92172DL and ICSR 160 were found to be sources of genes for early maturity.Desirable GCA values of parents ICSR 24010, ICSR 24008, Macia and ICSR 160 for grain yield showed that they can be good sources of genes for improving grain yield. High GCA values of parents ICSV 700, KARI Mtama 1, Hakika, and Macia for biomass yield indicated that these parents had favourable genes, hence could be used to improve fodder yield through hybridization.

The estimates of the SCA effects of females within males revealed that no cross combination was superior for all characters. The hybrids ATX623 x Macia, ICSA 11040 x IESV 91104DL, and ICSA 29011 x ICSR 89058exhibited SCA effects in the desirable direction forgrain yield, days to flowering, biomass yield, panicle exertion, plant height and seed set. These hybrids also showed good *per se* performance for grain yield. Therefore, these crosses can be fast-tracked for on-farm testing and possible release. Chikuta *et al* (2017) reported negative and positive SCA effects in sorghum hybrids. The late flowering hybrid ICSA 11036 x KARI Mtama 1 withthe most desirableSCA effect for biomass yield also revealed good*per se* performance for the trait. Howeverit recorded the lowest SCA for grain yield, therefore, it could be utilised in the forage sorghum improvement program. The findings in the present study on forage yield are consistent with the earlier findings of Desai *et al*. (2000) &Ghulam and Shahid (2014).

Additive gene action was predominant over non-additive gene action for grain yield, biomass yield, leaf width, number of plants lodged, and number of tillers, panicle length, panicle width, panicle exertion, plant height, 100 seed mass, and seed set. Similar results were earlier reported by Kale and Desai (2016), Riyazaddin*et al*., (2015), and Mungra*et al*., (2011). However, the expression of days to 50% flowering, leaf length and stem girth was controlled by non-additive gene action. Muturi (2013) reported significant non-additive gene action for panicle emergence and length whereas Mungra*et al*., (2011) reported that non-additive gene action played a major role in the inheritance of plant height and stem fodder yield. This shows that both additive and non-additive gene actions are important in governing the inheritance of yield and its component traits. Hence, there is a possibility of improving grain and forage yield through hybrid breeding.

CONCLUSIONS

Environment affected the genotypic expression of hybrids and their parents for most of the traits. Therefore, the selection of new hybrids and their parents should be done on the basis of specific and broad adaptation. Additive gene action influenced the inheritance of grain yield, biomass yield, the number of productive tillers, panicle length, width and exertion, plant height, seed set, and 100 seed mass. Non-additive gene action controlled the inheritance of days to 50% flowering, leaf length, and the stem girth. High heritability (h^2) estimates were observed for days to flowering, panicle exertion, plant height, and biomass yield hence there could be positive response to direct phenotypic selection of these traits. GCA analysis showed that lines ICSR 89058, ICSR 38, IESV 92172DL and ICSR 160 were good general combiners for days to flowering hence could be used as sources of genes for earliness. Lines ICSR 24010, ICSR 24008, Macia and ICSR 160 were good general combiners for grain yield hence could be used to develop hybrids. Parents ICSV 700, KARI Mtama 1, Hakika, and Macia were the best combiners for biomass yield hence could be utilized in forage yield improvement. Development of early, high yielding dual purpose sorghum hybrids is possible through the exploitation of heterosis. Cross combinations ATX623 x Macia, ICSA 11040 x IESV 91104DL, and ICSA 29011 x ICSR 89058were high yielding. They had good combining ability for grain yield, days to flowering, biomass yield, panicle exertion, plant height and seed set. These hybrids can be investigated further through on-farm testing and possible commercial release.

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